# Drip Irrigated Cotton: Irrigation Scheduling Study by use of Soil Moisture Neutron Probe

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FRENCH

**ETUDE SUR LES HORAIRES D'IRRIGATION AU GOUTTE À GOUTTE DU COTON, EXÉCUTÉE AU MOYEN D'UNE SONDE À NEUTRON MESURANT L'HUMIDITÉ DU SOL**

Des recherches sur l'utilisation de l'eau (évapotranspiration ou ET) et les horaires d'irrigation au goutte à goutte du coton ont été menées à la Station Centrale d'Expérimentation de l'Institut de Recherche sur la Culture du Coton en Ouzbekistan (UNCGRI), sur le vieux sol gris typique (un terreau vaseux et profond), en 2000 et 2001.
La consommation d'eau a été établie en étudiant l'équilibre sol-eau sur une base hebdomadaire. On a procédé à des mesures en profondeur du contenu en eau du profil du sol, en utilisant des sondes à neutrons pour mesurer l'humidité. Ces sondes étaient calibrées dans des tubes d'accès en PVC pour le sol et pour chaque horizon. On a mesuré la quantité d'eau dans le sol afin de déterminer les débits et les temps d'irrigation pour le coton alimenté au goutte à goutte durant la saison de croissance. Le rendement du coton a été augmenté de 21 à 22 %.

## Introduction

Cotton and wheat are the major crops in Uzbekistan followed by corn, alfalfa, sugar beet, vegetables and fruits. About 60%of the country is (semi-) desert with only four million hectares of the area cropped. With annual rainfall of 110 to 220 mm, Uzbekistan's climate is that of the dry mid-latitude desert, which is characterized by hot summers and cold winters. Thus, agricultural production in the country, like in the whole of Central Asia, is predominantly based on irrigation, which makes irrigation water supply and management the prevailing factors limiting crop yields in the region.

Agriculture in Uzbekistan was and still is the largest sector in Uzbekistan's economy. Water, used for hydro-electricity generation and irrigation, is supplied by two major river systems: the Amu-Darya and Syr-Darya, which also supply the neighboring countries of Kyrgyzstan, Tajikistan, Afganistan, Turkmenistan and parts of Kazakhstan. Since 1991, these Central Asian countries have continued their dispute on meeting increasing water demands. Since then, lack of water has gradually devastated the irrigation-dependent cotton, winter wheat and other major crop production. In addition, lack of water has engendered the ecological catastrophe within the Aral Sea

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*First author Bakhtiyor Kamilov checking an access tube for standing water at a wet site prior to neutron probe calibration measurements.*

Basin, at the tail end of the river systems of Uzbekistan.

Investigation of crop water scheduling in relation to lack of irrigation water has not been conducted in Uzbekistan. The main goal of this research was to measure cotton water use in Uzbekistan, and to determine irrigation scheduling parameters associated with optimal yield and irrigation water use efficiency.

## Materials and methods

The field experiment was conducted at the Central Experiment Station of Uzbekistan's National Cotton Growing Research Institute (UNCGRI) in 2000 and 2001 at Tashkent. The soil is an old irrigated typical gray soil, a silt loam; and the water table is more than 15-m deep (automorphic type of soil formation). As a starting point for investigations of irrigation scheduling, we adopted the field capacity ($F_C$) index, which was 0.298 $m^3$ $m^{-3}$ in this soil. Irrigations were scheduled when soil moisture in the root zone was depleted by the crop to specific fractions of $F_C$ (for instance, irrigation at 70% of $F_C$) for each of the three main plant growth periods defined below.

The experiment with cotton was carried out in three replicates and comprised two irrigation scheduling treatments with drip irrigation, and one treatment with surface irrigation for comparison. The drip irrigation system, comprising one line of surface drip tape per row, was installed in the field after completion of early season inter-row cultivation. Each treatment consisted of scheduling irrigations at specific percentages of $F_C$ during each of three plant growth periods as follows:

1. 65-65-60 % of $F_C$ (drip irrigation)
2. 70-70-60 % of $F_C$ (drip irrigation)
3. 70-70-60 % of $F_C$ (conventional irrigation)

where the first of the three levels of $F_C$ (e.g., **65**-65-60 %) was used from germination to squaring stage of the crop; the second level (e.g., 65-**65**-60 %) was used from squaring to the flowering-fruiting stage; and the third level (e.g., 65-65-**60** %) was used during maturation of cotton bolls. Each replicated plot was 240 m 2 (4.8 m by 50 m). Irrigation water quantity applied through drip irrigation was measured by an in-line propeller-type flow meter. Water quantity for the surface irrigation treatment was measured using the weir of Chippoletty. Fertilizer was applied at rates of 200 kg $ha^{-1}$ N, 140 kg $ha^{-1}$ P, and 100 kg $ha^{-1}$ K.

Cotton water use was measured by the soil water balance method. Considering *ET* as crop water use, *P* as precipitation, *I* as Irrigation, *R* as the sum of runoff and run-on, *F* as flux across the lower boundary of the soil profile (control volume), and $\Delta S$ as change in soil water stored in the profile, we know that the soil water balance must sum up to zero:

$$ET + \Delta S + R - P - I - F = 0 \qquad (1)$$

where the sign conventions are as given in Evett (2002), including the convention that *ET* is taken as positive when water is lost to the atmosphere through transpiration and/or evaporation. Re-arranging this equation gives the crop water use or *ET* as:

$$ET = -\Delta S + P + I - R + F \qquad (2)$$

A key thrust of our investigations was the measurement of soil profile water content. For this purpose we used the soil moisture neutron probe (SMNP) (Campbell Pacific Nuclear International, model Hydroprobe-503DR1.5), which was calibrated for each soil and soil horizon using methods described in Evett and Steiner (1995). For calibration, polyvinyl chloride (PVC) access tubes were installed in the field to 2.0-m depth, in two replicates in each of two plots

**Table 1. Calibration equations for soil moisture neutron probe (SMNP) for Tashkent. Measurements were at 20-cm increments at and between depths noted below. Equations are in terms of volumetric water content ($\theta$, $m^3$ $m^{-3}$) and count ratio ($C_R$).**

| Location | Depth (cm) | Equation | $r^2$ | RMSE* ($m^3$ $m^{-3}$) |
|---|---|---|---|---|
| | 10 | $\theta = 0.013 + 1.1752C_R$ | 0.989 | 0.011 |
| Tashkent #H390104791** | 30 – 70 | $\theta = -0.176 + 0.3759C_R$ | 0.958 | 0.014 |
| | 90 – 170 | $\theta = -0.039 + 0.2463C_R$ | 0.911 | 0.010 |

* RMSE is root mean squared error of regression.
** The # sign denotes the SMNP serial number.

Table 2. Volumetric water content of the old irrigated typical gray soil at the beginning and the end of vegetation (Tashkent, cotton)

| | Volumetric water content ($m^3\ m^{-3}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2000 | | | | 2001 | | | |
| | | At end of growing season | | | | At end of growing season | | |
| | | Drip irrigation | | Surface irrigation | | Drip irrigation | | Surface irrigation |
| Soil layer (cm) | 2000 at crop emergence | 65-65-60% $F_C$ | 70-70-60% $F_C$ | 70-70-60% $F_C$ | 2001 at crop emergence | 65-65-60% $F_C$ | 70-70-60% $F_C$ | 70-70-60% $F_C$ |
| 30 | 0.276 | 0.222 | 0.235 | 0.226 | 0.284 | 0.247 | 0.249 | 0.238 |
| 50 | 0.295 | 0.230 | 0.259 | 0.261 | 0.330 | 0.258 | 0.312 | 0.304 |
| 70 | 0.329 | 0.256 | 0.270 | 0.244 | 0.341 | 0.303 | 0.323 | 0.336 |
| 90 | 0.355 | 0.293 | 0.312 | 0.278 | 0.344 | 0.300 | 0.349 | 0.341 |
| 110 | 0.347 | 0.285 | 0.319 | 0.301 | 0.314 | 0.278 | 0.311 | 0.326 |
| 130 | 0.361 | 0.304 | 0.325 | 0.326 | 0.305 | 0.280 | 0.328 | 0.344 |
| 150 | 0.366 | 0.315 | 0.347 | 0.319 | 0.316 | 0.299 | 0.334 | 0.352 |
| 170 | 0.373 | 0.324 | 0.362 | 0.335 | 0.388 | 0.314 | 0.334 | 0.354 |

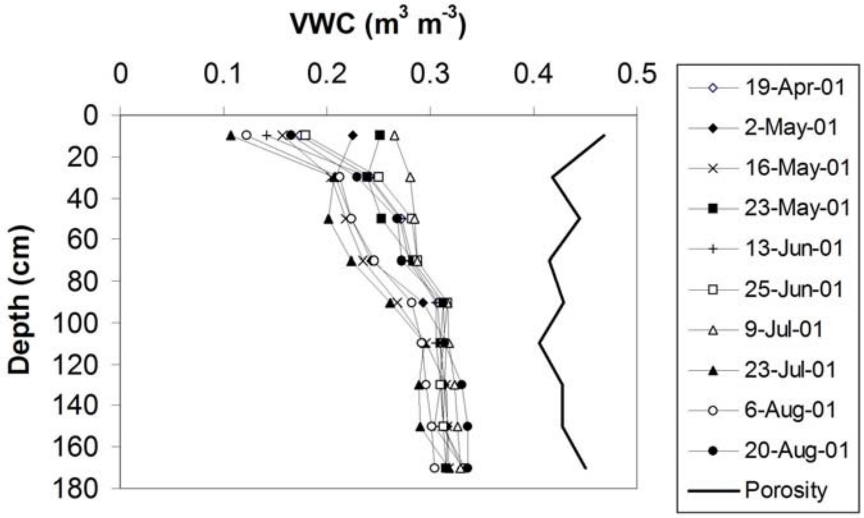


*Figure 1. Profile water content values from April through August 20, 2001 were always well below the saturated water content as indicated by the soil porosity.*

of 10 square meters each. A wet site plot was irrigated to field capacity to below the 2-m depth using irrigation water (Fig. 1). A non-irrigated plot was prepared as the dry site by crop and field management during the preceding season. Volumetric water content of the soil profiles was measured by volumetric/gravimetric methods for comparison with count ratios measured with the SMNP. Calibration equations were calculated for the important soil layers. These were used for determination of profile water content and thus calculation of irrigation rates and times for cotton during the growing season. Measurements of volumetric water content of the soil profile were conducted twice a week and in two replicates during the experiments by SMNP to 2-m depth and for each 20-cm soil layer separately. Before each measurement, a standard count ($C_S$) of the SMNP was determined in five replicates.

## Results and discussion

### *SMNP Calibration*

Reasonably precise calibration equations were obtained for all soil horizons. The root mean squared error (RMSE) of regression ranged from 0.010 to 0.014 $m^3\ m^{-3}$ (Table 1). Distinctly different soil horizons were identified. Also, due to nearness to the surface, equations for the 10-cm depth were different in slope from equations for deeper layers. The old irrigated gray soil of Tashkent Province is uniform in texture, ranging from silt to silty clay loam throughout the profile, and is probably derived from loess, either in place or in alluvial deposits. Nodules and veins of $CaCO_3$ were noted during sampling at depths of >70 cm. Since the soil is a uniform silt loam, the different calibration curve for depths >70 cm is probably due to the increase in $CaCO_3$ concentration. Similar effects of calcium minerals on SMNP calibration slopes have also been noted in the semi-arid Great Plains of the United States, where slopes were likewise lower for soil layers rich in $CaCO_3$ (Evett and Steiner, 1995; Evett, 2000). The effect is probably due to the presence of oxygen in these minerals, which is relatively effective in causing thermalization of fast neutrons. The lowered calibration slope values would be expected in this case because the presence of oxygen would increase the concentration of thermal neutrons and thus increase neutron counts without the presence of water.

### *Crop Water Use*

Throughout the season, water content remained well below the maximum allowed by the soil porosity, which was calculated from measured bulk density (Fig. 2). Application of the soil water balance equation, using measured irrigation, rainfall and soil water content changes, allowed calculation of seasonal water use. Values of $R$ and $F$ were assumed to be zero for our experimental conditions. Precipitation data ($P$) were taken from the Meteorological Station of the Institute, which is located at the Central Experiment Station. During the cotton vegetation season precipitation was 64 mm and 27 mm in 2000 and 2001, respectively. Values of change in soil water stored in the profile ($\Delta S$) were calculated with the use of the integral calculus method and data from Table 2. Values of water content at the beginning of each growing season were similar in all treatments and so were lumped across treatments in Table 2. Having calculated the $\Delta S$ for each treatment of the experiment, we determined the ET for the 0 to 150-cm deep soil control volume (Table 3).

Results of the experiment showed that, for drip irrigated treatments, top yield in both years was reached for treatment 2 (Table 4). Treatment 1 was considered to be deficit scheduling of irrigation due to its lower yield. For drip irrigation, additional yield received (average for two years) with treatment 2 (75-75-60 % of $F_C$) in comparison with scheduling of irrigation at 65-65-60 % of $F_C$ was 0.43 t $ha^{-1}$ (13.4% increase). Average additional yield for drip irrigation compared with surface irrigation was 0.65 t $ha^{-1}$ (21.7%increase) using the same irrigation scheduling treatment of 70-70-60 % of $F_C$. Moreover, irrigation water use efficiency was always larger for drip irrigation than for furrow irrigation.

Some experiments have shown that drip irrigation does not increase cotton yield relative to well-managed surface irrigation (Howell et al., 1987; Bucks et al., 1988). Others have shown that drip irrigation may increase lint yields and water use efficiency

Table 3. Water use (*ET*) of cotton in Tashkent.

| Treat-ment # | % of $F_C$ Treatments | Irrigation Method | 2000 $\Delta S$ (mm) | 2000 Irrigation (mm) | 2000 *ET* (mm) | 2001 $\Delta S$ (mm) | 2001 Irrigation (mm) | 2001 *ET* (mm) |
|---|---|---|---|---|---|---|---|---|
| 1 | 65-65-60% | Drip | 105 | 225 | 183 | 76 | 330 | 281 |
| 2 | 70-70-60% | Drip | 63 | 250 | 251 | 23.4 | 375 | 379 |
| 3 | 70-70-60% | Surface | 92 | 410 | 381 | 14.6 | 542 | 554 |

Table 4. Irrigation and productivity of cotton at two locations in Uzbekistan

| Treatment # | Treatment (% $F_C$) | Irrigation method | Irrigation ($m^3$ $ha^{-1}$) | Seed cotton yield (t $ha^{-1}$) | Irrigation water requirement ($m^3$ $t^{-1}$) | Irrigation water use efficiency (kg $m^{-3}$) |
|---|---|---|---|---|---|---|
| | | | Year of 2000 | | | |
| 1 | 65-65-60 | Drip | 2250 | 3.12 | 721 | 1.38 |
| 2 | 70-70-60 | Drip | 2500 | 3.60 | 694 | 1.44 |
| 3 | 70-70-60 | Furrow | 4100 | 2.95 | 1390 | 0.71 |
| | | | Year of 2001 | | | |
| 1 | 65-65-60 | Drip | 3300 | 3.29 | 1003 | 0.99 |
| 2 | 70-70-60 | Drip | 3750 | 3.67 | 1022 | 0.97 |
| 3 | 70-70-60 | Furrow | 5420 | 3.02 | 1750 | 0.55 |
| Treatment # | Treatment (% $F_C$) | Irrigation method | *ET* ($m^3$ $ha^{-1}$) | Seed cotton yield (t $ha^{-1}$) | Total water requirement ($m^3$ $t^{-1}$) | Total water use efficiency (kg $m^{-3}$) |
| | | | Year of 2000 | | | |
| 1 | 65-65-60 | Drip | 1832 | 3.12 | 587 | 1.70 |
| 2 | 70-70-60 | Drip | 2508 | 3.60 | 697 | 1.44 |
| 3 | 70-70-60 | Furrow | 3812 | 2.95 | 1292 | 0.77 |
| | | | Year of 2001 | | | |
| 1 | 65-65-60 | Drip | 2810 | 3.29 | 854 | 1.17 |
| 2 | 70-70-60 | Drip | 3786 | 3.67 | 1032 | 0.97 |
| 3 | 70-70-60 | Furrow | 5544 | 3.02 | 1836 | 0.54 |

by large amounts compared with those from sprinkler or surface irrigation (Bordovsky, 2001; Smith et al., 1991). In our experiment, drip irrigation showed its superiority over conventional surface irrigation. Therefore, drip irrigation should be further explored as an effective means to control quantity of irrigation water.

## Conclusions

1. Overall, our investigations with cotton conducted in the old irrigated typical gray soil of Tashkent Province showed that calibration of the SMNP was successful and acceptably precise for research objectives. The SMNP was useful for determining water content dynamics of soil profiles, scheduling irrigation during growing seasons, and obtaining accurate data on water use.
2. For two years, scheduling drip irrigation following the 70-70-60% of $F_C$ treatment resulted in saving 31 to 39% of the irrigation water in comparison with surface irrigated cotton grown under the same conditions. Irrigation water use efficiency was increased by 76 to 103% compared with that of surface irrigation when scheduling was done using the (70-70-60% of $F_C$) rule for both. The seed-cotton yield was increased by 21 to 22% relative to the surface irrigated cotton.

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